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THE DRAWING UP OF THE MOTION SCHEDULE IN THE INTELLIGENT URBAN PASSENGER TRANSPORT SYSTEM

Shuts Vasily[1], Shviatsova Alena[2]
[1, 2] Brest State Technical University, Moskovskaya, 267, 224017, Brest, Belarus

[1] http://orcid.org/ 0000-0002-7979-6157
[2] http://orcid.org/ 0000-0002-1613-6645

Abstract. This article is devoted to description of the basic principles of constructing a motion schedule in an intelligent urban passenger transport system based on robotic vehicles, which ensures the non-conflict motion of unmanned vehicles, in which the vehicles in front do not delay those following them. In the introduction of the article, a description of the basic problems of modern urban passenger transport systems and the formulation of the research targets are given. The section "Principles of ITS function" provides a description of the transport system concept and principles of functioning for the aim that the reader can receive a holistic view of the research subject. A basic characteristic features of this intelligent urban passenger transport system are that ITS is capable of timely adjusting to changes in demand for transportation, because processes occurring in the transport system (collection of service requests, data processing and analysis, planning and organization of transportation) are cyclical and are carried out in real time. The drawing up of the movement schedule of vehicles also occurs in real time. In the section "Drawing up a traffic schedule of vehicles" the basic principles of constructing a vehicles traffic schedule are given and their usage is demonstrated with a specific example. The introduction in usage this intelligent city passenger transport system, built on the proposed principles, will allow to get technology of passenger transportation that able to adaptive changes of number autonomous transport units that are used in transportation, depending on the demand for transportation. Such approach allows both to fully and timely satisfy the needs of passengers, and to save the resources of the transport system, what is the main aim of each passenger transport system.

Keywords: cassette transportation method, intelligent transport, smart transport, information transport system, transport with divided parts, organization of transportation, scheduling.

СКЛАД ГРАФІКА РУХУ В ІНТЕЛЕКТУАЛЬНІЙ МІСЬКІЙ ПАСАЖИРСЬКІЙ ТРАНСПОРТНІЙ СИСТЕМІ

В. М. Шуть[1], О. В. Швецова[2]
[1, 2] Брестський державний технічний університет, вул. Московська, 267, м. Брест, Білорусь, 224017

[1] http://orcid.org/ 0000-0002-7979-6157
[2] http://orcid.org/ 0000-0002-1613-6645

Анотація. Стаття присвячена опису основних принципів побудови графіка руху в інтелектуальній міській пасажирській транспортній системі на базі роботизованих транспортних засобів, що забезпечує безконфліктний рух безпілотних транспортних засобів, при якому транспортні засоби, що йдуть попереду, не затримують наступних за ними.

У вступі статті дається опис основних проблем сучасних систем міського пасажирського транспорту та формулювання мети дослідження. У розділі "Принципи функціонування ІТС" надається концепція транспортної системи та принципи її функціонування для того, щоб читач міг отримати цілісне уявлення про предмет дослідження. Основною відмінною особливістю наведеної інтелектуальної системи міського пасажирського транспорту є те, що ІТС здатна своєчасно підлаштовуватися під зміни попиту на перевезення, оскільки процеси, що відбуваються в транспортній системі (збір заявок на обслуговування, обробка та аналіз даних, планування та організація перевезень) циклічні та здійснюються в режимі реального часу. Складання графіка руху транспортних засобів також відбувається у режимі реального часу. У розділі "Складання графіка руху транспортних засобів" наведено основні принципи побудови графіка руху та продемонстровано їх використання на конкретному прикладі. Впровадження даної інтелектуальної системи міського пасажирського транспорту,

побудованої на запропонованих принципах, дозволить отримати технологію пасажирських перевезень, здатну змінювати кількість автономних транспортних одиниць, які беруть участь у перевезеннях, залежно від попиту перевезення. Такий підхід дозволяє як повністю та своєчасно задовольняти потреби пасажирів, так і економити ресурси транспортної системи, що є основною метою кожної пасажирської транспортної системи.

Ключові слова: касетний метод перевезення, інтелектуальний транспорт, розумний транспорт, інформаційна транспортна система, транспорт з частинами, що мають поділ, організація перевезень, складання графіка руху.

Introduction

Modern urban public transport has the following disadvantages:

- making ineffective decisions on traffic dispatching due to the lack of timely and accurate information about the demand for transportation, which inevitably leads to an imbalance in the occupancy of vehicle interiors: at peak moments of demand for transportation, the saloons are overcrowded, and the rest of the time the vehicles run almost half empty.

- the existing nomenclature of vehicles is focused on meeting the demand for transportation at the peak moments of the transport system, which leads to their ineffective use during periods of decline in demand for transportation.

These problems can be successfully solved by introducing information and transport systems (ITS) using modern intelligent technologies capable of collecting and analyzing data on the demand for transportation in real time, as well as using autonomous transport modules of small capacity, capable of combining autocaravans. [1]. This is how projects of urban passenger transport systems are being implemented, which are based on the principles of autonomous mobile modules that can, if necessary, combine and move together: Next Future Transportataion (Italy) [2] and DART (Dynamic Autonomous Rapid Transit, Singapore) [3]. These approaches will increase the degree of timely satisfaction of the demand for transportation with the most rational use of the resources of the transport system.

The purpose of this work is to describe the principles of constructing a real-time schedule for the movement of vehicles in ITS based on unmanned electric vehicles in accordance with the passenger transportation plan.

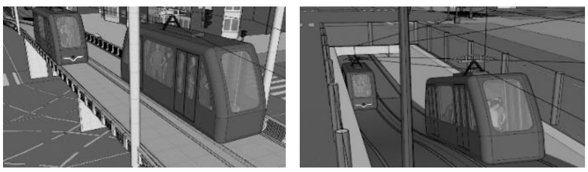
Principles of ITS function

The proposed urban passenger information transportation system is based on unmanned electric vehicles are called infobuses. It was described in detail in works [4-10]. The ITS includes:

- a fleet of small capacity unmanned vehicles (6-21 seats) called infobuses. Each infobus is controlled by its own on-board computer system, which receives control from a information server of the ITS (IS ITS). Vehicles move along a dedicated path (rails, dedicated line, etc.). That approach makes traffic of infobuses a high priority. Infobuses can move both separately and together according to the caravan principle. Together, the infobuses form a cassette (Fig. 1), which is a vehicle with separable parts [10]. This principle allows to form a vehicle with the necessary carrying capacity. Intersections by infobuses are crossed by traffic light regulation (according to the "green wave") or by means of overpasses (Fig. 2a) or through underground tunnels (Fig. 2b).

Fig.1. Infobus movement single and in cassette

- the bus route contains *k* stops (each in two directions) and the collection points for the infobuses (Assembly Point 1 and Assembly Point 2) from which the busses begin to execute the transportation plan and return to which after its implementation (Fig. 3).



a) by overpass b) by underground tunnels

Fig. 2. The movement of infobuses on a separate dedicated line

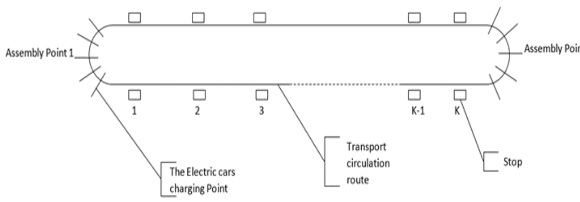


Fig. 3. The route of movement

- a system of terminals at stops (Fig. 4) and a mobile application that allow to register the requests from passengers for transportation.

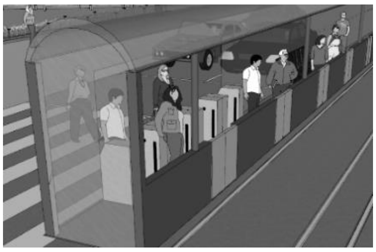


Fig. 4. System of terminals at stops

- information server ITS (IS ITS), which is a software and hardware complex is used for collecting, analyzing passenger requests and organizing passenger transportation in real time. The result of the organization of transportation process is a drawn up transportation plan, which is sent to the on-board infobus computer systems for execution. The software elements of the IS ITS are the following systems: Data Collection System (DCS), Data Analysis System (DAS) and Transportation Management System (TMS).

DCS is based on the use of stationary terminals at stops (Fig. 4) and applications for smartphones, with the help of which passengers can register requests for transportation in the ITS. The data storage layer in DCS is represented by the Time Series Database Management System (TSDB) because the flow of requests from passengers can be viewed as a *discrete time series* (here a time series is understood as a sequence of observations in chronological order are located on the time axis, if the time is measured discretely, then the series is also called discrete). Modern TSDBs support high-performance data insertion and processing and are successfully used in highly loaded distributed systems, which also include the considered ITS IS.

DAS provides analytical data derived from historical data accumulated in TSDB: information on correspondences, changes in traffic demand intensity in the context of time of day; day of week or month; holidays, pre-holiday days, etc. This analytics is used to organize the adaptive transport process, the information base of which consists of a matrix of correspondences M (Fig. 5), which is formed by the requests accumulated by the transport system. Each element m_{ij} of the matrix M is the sum of the seats number in requests for transportation from stop i to stop j and, as well as *forecast indicator*, that determines the volume of potential transportation requests that will be registered in the system during the time from the end of the collection passenger requests until the moment the vehicle arrives at the stop [9].

$$M = \begin{pmatrix} 0 & m_{12} & m_{13} & \dots & \dots & m_{1j} & \dots & m_{1k} \\ 0 & 0 & m_{23} & \dots & \dots & m_{2j} & \dots & m_{2k} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & \dots & 0 & m_{ii+1} & \dots & m_{ij} & \dots & m_{ik} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & \dots & \dots & \dots & \dots & \dots & 0 & m_{k-1k} \\ 0 & \dots & \dots & \dots & \dots & \dots & \dots & 0 \end{pmatrix}$$

Fig. 5. Matrix of correspondences M

The generated matrix of correspondences is transferred to the TMS for drawing up a plan for the transportation of passengers. The transportation plan is drawn up for each participating vehicle and includes: an identification number for each infobus; origin stop (the stop from which the infobus will initially pick up passengers); the set of target stops (to which the infobus will take passengers); motion schedule for each vehicle. The generated transportation plans are forwarded to the on-board infobus systems for execution.

Thus, the functioning of the system is cyclic and consists of the data collecting process, the drawing up a transportation plan process and sending it to the infobuses and the process of implementing the plan. Fig. 6 shows the scheme of ITS functioning.

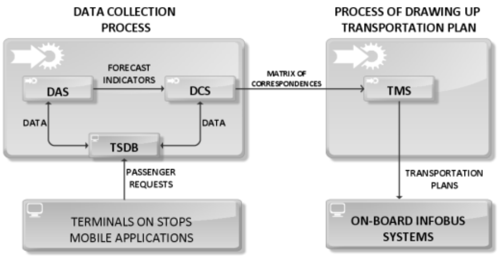


Fig. 6. ITS functioning scheme

Drawing up a traffic schedule of vehicles

The ITS under consideration belongs to the class of PRT (Personal Rapid Transit) systems, the characteristic feature of which is transportation in the origin-destination mode, where the source is the stop where the passenger sat down and the destination is where the passenger goes. In this mode of transportation, unlike classic urban public transport, passengers get to the destination stop with a minimum number of intermediate stops where they do not have to get off. Therefore, each infobus that participates in caring out the transportation plan, in addition to the identification number n_i (where n is the serial number of the infobus, and the i-stop is the source) also receives

the source stop and the set of target stops J_{n_i} to which it will take passengers who sat at stop *i*.

The movement of vehicles on the route should be mostly conflict-free, i.e., infobuses should not delay each other. In [11], a criterion to detect potential traffic conflicts was formulated. Here, a conflict of traffic is understood as a situation where the vehicle behind is forced to idle due to delays associated with the following vehicle ahead.

The set of target stops J_{n_i} of any infobus has its own power, which directly affects the idle time that will be spent by the infobus at stops and can be found from the relation $(|J_{n_i}|+1)\cdot t_{st}$, where t_{st} - idle time at a stop (the value is known and constant), and the one added to the absolute value implies the source stop. The accumulated idle time at a stop $j, j=\overline{1,k}$ is the cumulative time that is spent on idle at previous stops before stop *j*, including idle time at stop *j* itself. The accumulated idle time of infobuses that move at the same speed affects their convergence-removal during the transit. The conflict of movement occurs at the stop where the accumulated idle time of the ahead infobus exceeds the accumulated idle time of the behind infobus. This situation can be solved by displacement the start time of the behind infobus relative to the previous one so as to exclude the delays of the behind. This section discusses the principles of construction of the infobus schedule, which provides this.

For each infobus, when drawing up a transportation plan, together with a set of stops J_{n_i} a vector of arrival time at stopping points $d_{n_i}=(d^0_{n_i}, d^1_{n_i}, ..., d^{j-1}_{n_i}, d^j_{n_i}), j=\overline{1,k}$ and a vector of departures from stopping points $a_{n_i}=(a^0_{n_i}, a^1_{n_i}, a^2_{n_i}, ..., a^{j-1}_{n_i}, a^j_{n_i}), j=\overline{1,k}$ are compiled, where $d^j_{n_i}, a^j_{n_i}$ - are the time of departure from stop *j* and arrival to stop *j* of the infobus, respectively. To find the coordinates of the vectors d_{n_i}, a_{n_i}, a vector of distances from Assembly point 1 to the other stops of the route and Assembly point 2 must be introduced. The coordinates of this vector are computed one time known and don't change (the sequential number of Assembly point 1 is equal to 0, and to Assembly point 2 - *(k + 1)*):

$$S=(S_{00}, S_{01}, S_{02}, ..., S_{0k}, S_{0k+1}), \qquad (1)$$

where $S_{0j}, j=\overline{0,k+1}$ is the distance between stop 0 and stop *j*.

The vector of the time to reach the stops of the route with the non-stop movement of the infobus is found from the ratio:

$$t=(t_{00}, t_{01}, t_{02}, ..., t_{0k+1})=(0, \frac{s_{01}}{v}, \frac{s_{02}}{v}, ..., \frac{s_{0k+1}}{v}), \qquad (2)$$

where *v* is the speed of the infobuses, which is a constant and known in advance.

Then the coordinates $d^j_{n_i}$ and $a^j_{n_i}, j=\overline{1,k+1}$, the vector of departures d_{n_i} and the vector of arrivals a_{n_i} of the infobus n_i, participating in the execution of the transportation plan, are found, respectively, as:

$$a^j_{n_i}=t_{start}+t_{0j}+t_{st}\cdot q^j_{n_i}, j=\overline{0,k+1} \qquad (3)$$

$$d^j_{n_i}=\begin{cases} t_{start}+t_{0j}+t_{st}\cdot(q^j_{n_i}+1), j=\overline{0,k+1}, j\in J_{n_i} \\ a^j_{n_i}, j\notin J_{n_i} \end{cases} \qquad (4)$$

where t_{start} is the start time of the current transportation plan, which is formed in the TMS as a result of the process of drawing up the transportation plan (Fig. 6) as the sum of the moment of fixing the transportation plan in the system, the time for sending this plan to the on-board infobus systems (this value is constant and known), and the time for the on-board systems to make the infobuses ready for the implementation of the vehicle transportation plan (this value is constant and known). t_{0j} is the coordinate of the vector *t* corresponding to the stop *j*; t_{st} - idle time at a stop (constant and known value); $q^j_{n_i}$ - the number of stops made by the infobus before stop *j*. Thus, the value $t_{st}\cdot(q^j_{n_i}+1)$ corresponds to the accumulated idle time of the infobus to stop *j*. If stop *j* is included in the set of target stops of the infobus J_{n_i}, then the time of departure of the vehicle from it increases by t_{st} in relation to the time $d^j_{n_i}$, otherwise, that is $a^j_{n_i}=d^j_{n_i}$, i.e. the infobus passes this stop without stopping.

Two consecutive infobuses will follow without conflict during the execution of the transportation plan, if the difference between the vector a_{n_i} of arrival time at stops back infobus n_i (*i* - source stop for infobus n_i) and the vector $d_{(n-1)_{i^*}}$ of departures from stops in front of the infobus $(n-1)_{i^*}$ (i^* - source stop for infobus

$(n-1)_{i^*}$) will have non-negativity coordinates:

$$a_{n_i} - d_{(n-1)_{i^*}} = (a^0_{n_i} - d^0_{(n-1)_{i^*}}, ..., a^{k+1}_{n_i} - d^{k+1}_{(n-1)_{i^*}}),\\ i, i^* = \overline{1, k-1} \quad (5)$$

The negativity of the vector coordinates $a_{n_i} - d_{(n-1)_{i^*}}$ indicates that the back infobus n_i, will appear at the stops which are according negativity coordinates earlier than the previous infobus will departure, what shouldn't happen.

To exclude conflicts of follow, the maximum module among the negative coordinates of the vector $a_{n_i} - d_{(n-1)_{i^*}}$ must be found when drawing the schedule of motion:

$$\Theta = \max\{| d^j_{n_i} - a^j_{(n-1)_{i^*}} |\};\\ (d^j_{n_i} - a^j_{(n-1)_{i^*}}) < 0;\ j = \overline{0, k+1}; i, i^* = \overline{1, k-1}, \quad (6)$$

The found value Θ must be added to all coordinates of vectors d_{n_i} and a_{n_i} (back infobus n_i), which leads to an offset in the start time of the infobus n_i relative to the previous infobus $(n-1)_{i^*}$ by a time interval:

$$\begin{cases} d_{n_i} = (d^0_{n_i} + \Theta, d^1_{n_i} + \Theta, ..., d^{k+1}_{n_i} + \Theta) \\ a_{n_i} = (a^0_{n_i} + \Theta, a^1_{n_i} + \Theta, ..., a^{k+1}_{n_i} + \Theta) \end{cases}, \quad (7)$$

Thus, we get a schedule of the movement of the subsequent infobus in relation to the previous one, which ensures a conflict-free following.

Let's consider the scheduling of two infobuses that must follow each other during the implementation of the transportation plan.

The route will consist of seven stops (k = 7). The distances in meters from Assembly point 1 to stops are given by a vector $S = (0,110,1540,2530,3960,5500,6270,7370,7590)$, where the first coordinate corresponds to being in Assembly point 1, and the last one to the Assembly point 2. Time to stop t_{st} = 20 s. The speed of the infobuses $v = 40 km/h \approx 11 m/s$. Let t_{start} for simplicity of reasoning be equal to zero.

From formula (2) it follows that the coordinates of the travel time vector to the stops from the Assembly point 1, expressed in seconds, are: $t = (0,10,140,230,360,500,570,670,690)$.

Let in the realization of the transportation plan participate two infobuses 1_1 (it follows the first in the order and has the first stop as a source stop) and 2_3 (respectively, the second in the order with the source stop number three), the sets of target stops for which are the following $J_{1_1} = \{5,6,7\}$, $J_{2_3} = \{4,5\}$. So, the first infobus picks up passengers from the first stop and takes them to stops 5,6,7. And the second one picks up passengers from the third stop and takes them to stops 4 and 5. With the same speed motion and at the same start time from the Assembly point 1 the first infobus will delay the second one already at the first stop, because its accumulated idle time is longer. This can be seen from Table 1 and the infobus motion diagram (Fig. 7):

Table 1. Times of arrivals and departures

Arrivals	**Departures**
$a_{1_1} = (0,10,160,250,380,520,610,730,770)$	$d_{1_1} = (0,30,160,250,380,540,630,750,770)$
$a_{2_3} = (0,10,140,230,380,540,610,710,730)$	$d_{2_3} = (0,10,140,250,400,560,610,710,730)$

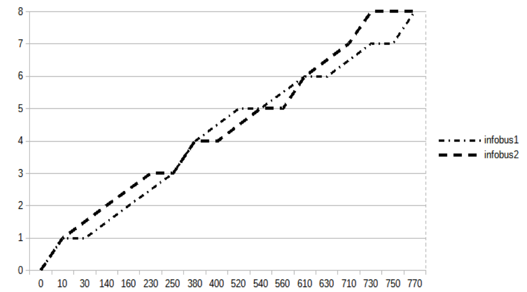


Fig. 7. Diagram of infobus movement

From the table and the diagram, we can see, that the motion of Infobus 2_3 will be delayed by Infobus 1_1 at the intervals of the route from stop 1 and to stop 3 and from stop 6 and up to the Assembly point 2.

To avoid conflicts in the execution of the transportation the difference between coordinates of the arrival vector of infobus 2_3 and departures vector of infobus 1_1 must be found, as well as the value Θ according to formulas (5,6):

$$a_{2_3} - d_{1_1} = (0, -20, -20, 0, 0, 0, 0, 0, -20, -40),\\ \Theta = \max\{| -20 |, | -40 |\} = 40$$

Thus, to eliminate the delay of the infobus 2_3, it is necessary to postpone its start time by 40 seconds, as a result of which the coordinates of the vectors and take the form:

$$d_{2_3} = (0,50,180,270,420,580,650,750,770)$$

$$a_{2_3} = (0,50,180,290,440,600,650,750,770)$$

Conflict-free vehicle following is reflected in the movement diagram in Fig. 8:

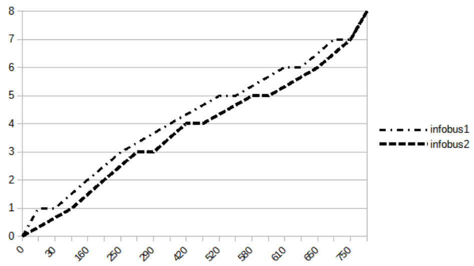


Fig.8. Diagram of the movement of infobuses after schedule changes

It can be seen from Figure 8 that throughout the following from the first to the seventh stop there will be a distance between the infobuses. At the seventh stop the infobuses will merge into a cassette, and so together will arrive at Assembly point 2.

Conclusion

The article proposes the general principles of scheduling conflict-free movement of vehicles in the execution of the transportation plan in the ITS based on unmanned electric vehicles, which allow you to plan the start time, arrival and departure of infobuses so that they do not delay each other during their movement along the route. The specific feature of transportation management in this information and transportation system is that the preparation of both the transportation plan and the schedule of movement of the vehicles involved in it is performed in real time.

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